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LV. *Conjectures concerning the Cause, and Observations upon the Phænomena of Earthquakes; particularly of that great Earthquake of the First of November, 1755, which proved so fatal to the City of Lisbon, and whose Effects were felt as far as Africa, and more or less throughout almost all Europe; by the Reverend John Michell, M. A. Fellow of Queen's College, Cambridge.*

# INTRODUCTION.

Read Feb. 28.  
March 6. 13.  
20. 27. 1760.

ART. I. **I**T has been the general opinion of philosophers, that earthquakes owe their origin to some sudden explosion in the internal parts of the earth. This opinion is very agreeable to the phænomena, which seem plainly to point out something of that kind. The conjectures, however, concerning the cause of such an explosion, have not been yet, I think, sufficiently supported by facts; nor have the more particular effects, which will arise from it, been traced out; and the connexion of them with the phænomena explained. To do this, is the intent of the following pages; and this we are now the better enabled to do, as the late dreadful earthquake of the 1st of November 1755 supplies us with more \* facts, and

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\* Many of these facts are collected together in the 49th volume of the Philosophical Transactions. The same are also to be found, with

and those better related, than any other earthquake of which we have an account.

2. That these concussions should owe their origin to something in the air, as it has sometimes been imagined, seems very ill to correspond with the phænomena. This, I apprehend, will sufficiently appear, as those phænomena are hereafter recounted; nor does there appear to be any such certain and regular connexion between earthquakes and the state of the air, when they happen, as is supposed by those who hold this opinion. It is said, for instance, that earthquakes always happen in calm still weather: but that this is not always so, may be seen in an account of the \* earthquakes in Sicily of 1693, where we are told, “ the south winds have blown very much, which  
“ still have been impetuous in the most sensible  
“ earthquakes, and the like has happened at other  
“ times.”

3. Other examples to the same purpose we have in an account of the earthquakes that happened in New England in 1727 and 1728; the author of

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with some additional ones, in “ The History and Philosophy of “ Earthquakes,” (a work well worth the perusal of those, who are desirous of being acquainted with this subject). The author of it has given us, besides the aforesaid facts, a very judicious abridgment of ten of the most considerable writers upon the subject. I have taken the greatest part of my authorities either from this author, or the Philosophical Transactions, that those who would wish to examine them, may have an opportunity of doing it the more easily; some things only, which were not to be met with in these, and which yet were necessary to my purpose, I have been obliged to seek for elsewhere.

\* See Philof. Transf. N<sup>o</sup> 207. or vol. ii. p. 408. Lowthorp’s Abridgment.

which

which says, that he could neither observe any connexion between the weather and the earthquakes, nor any prognostic of them; for that they happened alike in all kinds of weather, at all times of the tides, and at all times of the moon \*.

4. If, however, it should still be supposed, notwithstanding these instances to the contrary, that there is some general connexion between earthquakes and the weather, at the time when they happen, yet, surely, it is far more probable, that the air should be affected by the causes of earthquakes, than that the earth should be affected in so extraordinary a manner, and to so great a depth; and that this,

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\* See *Philos. Trans.* N° 409. or vol. vi. part ii. p. 202. Eames's Abridgment.—To these authorities, we may add the opinion of *Monf. Bertrand*, who expresses himself, upon this occasion, in the following manner. “Aristotle, Pliny, and Seneca, tell us, that earthquakes are preceded by a calm and serene air. This is, indeed, often the case, but not always. I don't know, upon an examination of the whole, if there are not as many exceptions to this rule, as examples that confirm it. Some authors again have thought, that they might look on a dark sky, lightnings, and sudden storms, as the forerunners of earthquakes.” Then relating some instances of shocks that happened in calm and serene weather, he adds, “On the other hand, it appears, from the examples, which we have before related, that many earthquakes have happened at the time of great rains, violent winds, and with a cloudy sky; so that one cannot find any certain prognostic of them in the state of the atmosphere.” See *Memoires Historiques et Physiques sur les tremblemens de Terre*, par *Monf. Bertrand*, a la Haye 1757. This author, in these sensible memoirs, has obliged the public with a circumstantial account of all the facts he could collect, relating to the earthquakes of Switzerland, or those of other places, that seemed to be connected with them. The whole seems to be done with care and fidelity, and without the least attachment to any particular system.

and all the other circumstances attending these motions, should be owing to some cause residing in the air.

5. Let us then, rejecting this hypothesis, suppose, that earthquakes have their origin under ground, and we need not go far in search of a cause, whose real existence in nature we have certain evidence of, and which is capable of producing all the appearances of these extraordinary motions. The cause I mean is subterraneous fires. These fires, if a large quantity of water should be let out upon them suddenly, may produce a vapour, whose quantity and elastic force may be fully sufficient for that purpose. The principal facts, from which I would prove, that these fires are the real cause of earthquakes, are as follow.

#### SECTION I.

6. *First*, The same places are subject to returns of earthquakes, not only at small intervals for some time after any considerable one has happened, but also at greater intervals of some ages.

7. Both these facts sufficiently appear, from the accounts we have of earthquakes. The tremblings and shocks of the earth at \* Jamaica in 1692, at \* Sicily in 1693, and at \* Lisbon in 1755, were repeated sometimes at larger, and sometimes at smaller intervals, for several months. The same thing has been observed in all other very violent earthquakes. At † Lima, from the 28th October 1746, to the

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\* See the accounts of these in the *Philos. Trans.*

† See Antonio d'Ulloa's *Voyage to Peru*, part ii. book i. ch. 7.

24th February 1747 (the time when the account of them was sent from thence), there had been numbered no less than 451 flocks, many of them little inferior to the first great one, which destroyed that city.

8. The returns of earthquakes also, in the same places, at larger distances of time, are confirmed by all history. Constantinople, and many parts of Asia Minor, have suffered by them, in many different ages: Sicily has been subject to them, as far back as the remains even of fabulous history can inform us of: Lisbon did not feel the effects of them for the first time in 1755: Jamaica has frequently been troubled with them, since the English first settled there; and the Spaniards, who were there before, used to build their houses of wood, and only one story high, for fear of them: \* Lima, Callao, and the parts adjacent, were almost totally destroyed by them twice, within the compass of about sixty years, scarce any building being left standing, and the latter being both times overflowed by the sea: nor were these the only instances of the like kind, which have happened there; for, from the year 1582 to 1746, they have had no less than sixteen very violent earthquakes, besides an infinity of less considerable ones; and the Spaniards, at their first settling there, were told by the old inhabitants, when they saw them building high houses, that they were building their own sepulchres †.

9. *Secondly,*

\* See the place above-quoted.

† What is here said, is taken from d'Ulloa's Voyage to Peru, the History and Philosophy of Earthquakes, the Philos. Trans. &c.  
where

9. *Secondly*, Those places that are in the neighbourhood of burning mountains, are always subject to frequent earthquakes; and the eruptions of those mountains, when violent, are generally attended with them.

10. Asia Minor and Constantinople may be looked upon as in the neighbourhood of Santerini. The countries also about \* *Ætna*, *Vesuvius*, mount *Hæcla*, &c. afford us sufficient proofs to the same purpose. But, of all the places in the known world, I suppose, no countries are so subject to earthquakes, as † *Peru*, *Chili*, and all the western parts of *South America*; nor is there any country in the known world so full of volcanos: for, throughout all that long range of mountains, known by the name of the *Andes*, from 45 degrees south latitude, to several degrees north of the line, as also throughout all *Mexico*, being about 5000 miles in extent, there is a continued chain of them ‡.

11. *Thirdly*, The motion of the earth in earthquakes is partly tremulous, and partly propagated by waves, which succeed one another sometimes at larger and sometimes at smaller

where many more examples, to the same purpose, are to be met with. See also *Memoires sur les tremblemens de Terre*; in which are mentioned above 130 repetitions of earthquakes, that have happened, within the compass of 960 years, in *Switzerland*.

\* See many instances of this in vol. ii. of *Lowthorp's Abr. of the Philos. Trans.*

† *Monf. Bouguer* says, that scarce a week passes without earthquakes in some part of *Peru*. See *Hist. of Earthq.* p. 205.

‡ See the Maps of these countries, *Condamine's Voyage down the Maranon*, *Acosta's Nat. Hist. of the Indies*, &c.

distances; and this latter motion is generally propagated much farther than the former.

12. The former part of this proposition wants no confirmation: for the proof of the latter, *viz.* the wave-like motion of the earth, we may appeal to many accounts of earthquakes: it was very remarkable in the two, which happened at Jamaica in \* 1687-8 and \* 1692. In an account of the former, it is said, that a gentleman there saw the ground rise like the sea in a wave, as the earthquake passed along, and that he could distinguish the effects of it, to some miles distance, by the motion of the tops of the trees on the hills. Again, in an account of the latter, it is said, "the ground heaved and swelled, like a rolling swelling sea," inasmuch, that people could hardly stand upon their legs by reason of it.

13. The same has been observed in the earthquakes of † New England, where it has been very remarkable. A gentleman giving an account of one, that happened there the 18th November 1755, says, the earth rose in a wave, which made the tops of the trees vibrate ten feet, and that he was forced to support himself, to avoid falling, whilst it was passing.

14. The same also was observed at ‡ Lisbon, in the earthquake of the 1st November 1755, as may be

\* See Phil. Trans. N<sup>o</sup> 209. or vol. ii. Lowthorp's Abridgment, p. 410.

† See Philof. Transf. vol. i. p. 1, &c.

‡ See the accounts collected together, in the 49th volume of the Philof. Transf. or in Hist. and Philof. of Earthq. and particularly p. 315. where it is said, "A most dreadful earthquake shook by  
" short,



be plainly collected from many of the accounts that have been published concerning it, some of which affirm it expressly: and this wave-like motion was propagated to far greater distances than the other tremulous one, being perceived by the motion of waters, and the hanging branches in churches, through all Germany, amongst the Alps, in Denmark, Sweden, Norway, and all over the British isles.

15. *Fourthly*, It is observed in places, which are subject to frequent earthquakes, that they generally come to one and the same place, from the same point of the compass. I may add also, that the velocity, with which they proceed, (as far as one can collect it from the accounts of them) is the same; but the velocity of the earthquakes of different countries is very different.

16. Thus all the shocks, that succeeded the first great one at Lisbon in 1755, as well as the first itself, came from the \* north-west. This is asserted by the person, who says, he was about writing a history of the earthquakes there: all the other accounts also confirm the same thing; for what some say, that they came from the north, and others, that they came

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“ short, but quick vibrations, the foundations of all Lisbon;  
 “ then, with a scarcely perceptible pause, the nature of the motion changed, and every building was tossed like a waggon  
 “ driven violently over rough stones, which laid in ruins almost  
 “ every house, church, &c.”

For the wave-like motion at Oporto, see Phil. Transf. vol. xlix. p. 418. for the same at Gibraltar, see Hist. and Philos. of Earthq. p. 322.

\* See Philos. Transf. vol. xlix. p. 410.

from the west, cannot be looked on as any reasonable objection to this, but rather the contrary. The velocity also, with which they were all propagated, was the same, being at least equal to that of sound; for they all followed \* immediately after the noise that preceded them, or rather the noise and the earthquake came together: and this velocity agrees very well with the intervals between the time when the first shock was felt at Lisbon, and the time when it was felt at other distant places, from the comparison of which, it seems to have travelled at the rate of more than † twenty miles *per* minute.

17. An historical account of the earthquakes, which have happened in ‡ New England, says, that, of five considerable ones, three are known to have come from the same point of the compass, *viz.* the north-west: it is uncertain from what point the other two came, but it is supposed that they came from the same with the former. The || velocity of these has been much less than that of the Lisbon earthquakes: this appears from the interval between the preceding noise, and the shock, as well as from the wave-like motion before-mentioned.

\* See *Philos. Transf.* vol. xlix. p. 414; or *Hist. and Philos. of Earthq.* p. 315.

† See Art. 97.

‡ See *Philos. Transf.* vol. 1. p. 9.

|| As in some earthquakes the velocity, with which they are propagated, is much less than in others, it is evident, that they can by no means be owing to any cause residing in the air: for any shock communicated to the air, must necessarily move with a velocity neither greater nor less than that of sounds; that is, at the rate of about thirteen miles *per* minute.

18. All the greater earthquakes, that have been felt at \* Jamaica, seem, by the accounts given of them, to have come from the sea, and, passing by Port-Royal, to have gone northwards. The velocity of these also was far short of the velocity of the Lisbon earthquakes.

19. The earthquake of † London, on the 8th of March 1750, was supposed to move from east to west. I have been credibly informed, that the same thing happened in a slight shock, which was felt there in the last century, as the person, who told me this, had an opportunity of observing; for being, by accident, in a scalemaker's shop at the time when it happened, he found that all the scales vibrated from east to west.

20. All the shocks that have been lately felt at Brigue in Valais, have likewise come from the same point of the compass, viz. the south ‡.

21. *Fifthly*, The great Lisbon earthquake has been succeeded by several local ones since, the extent of which has been much less.

22. Such were the earthquakes in Switzerland; those on the borders of France and Germany; those in Barbary, &c. ||

\* See the accounts of them in Philos. Transf. N° 209. or vol. ii. Lowthorp's Abr. p. 410, &c.

† See Hist. and Philos. of Earthq. p. 250. or Philos. Transf. vol. x. Martyn's Abr. Meteorology, passim.

‡ See Philos. Transf. vol. xlix. p. 620. The same has been observed at Smyrna also, see Philos. Transf. N° 495, or Martyn's Abr. vol. x. p. 526.

|| See the accounts of these collected together in Philos. Transf. vol. xlix. or in the Hist. and Philos. of Earthq.

## S E C T. II.

23. How well soever these facts may agree with the supposition before laid down, That subterraneous fires are the cause of earthquakes, one doubt, however, may perhaps remain; *viz.* how it is possible that fires should subsist, which have no communication with the outward air? In answer to this, I might alledge the example of green plants, which take fire by fermentation, when laid together in heaps; where the admission of the outward air is so far from being necessary, that it will effectually prevent their doing so. But, to pass by this, we have many instances more immediately to the purpose.

24. It can hardly be supposed, that the fires of the generality of volcanos receive any supply of fresh air (for this must effectually be prevented by that vapour, which is continually rushing out at all their vents), and yet they subsist, and frequently even increase, for many ages. Now, these are fires of the very same kind with those, which I suppose to be the cause of earthquakes. Other facts, still more expressly to the purpose, are as follow:

25. In the earthquake of the 1st of November 1755, we are told, that both smoke and light flames were seen on the coast of Portugal, near Colares; and that, upon occasion of some of the succeeding shocks, a slight smell of sulphur was perceived to accompany a "fog, which came from the sea, from the same "quarter, whence the smoke appeared\*."

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\* See Philos. Transf. vol. xlix. p. 414, &c.

26. In an account of an earthquake in New England, it is said, that at Newbury, forty miles from Boston, the earth opened, and threw up several cart-loads of sand and ashes; and that the sand was also slightly impregnated with sulphur, emitting a blue flame, when laid on burning coals\*.

27. One of the relaters of the earthquake in Jamaica in 1692, has these words: " In Port-Royal, " and in many places all over the island, much sulphureous combustible matter hath been found " (supposed to have been thrown out upon the " opening of the earth), which, upon the first touch " of fire, would flame and burn like a candle.

28. " St. Christopher's was heretofore much " troubled with earthquakes, which, upon the eruption there of a great mountain of combustible matter, which still continues, wholly ceased, and have " never been felt there since†."

29. Again, we are told, that, on the 20th November 1720, a burning ‡ island was raised out of the sea, near Tercera, one of the Azores, at which place, several houses were shaken down by an earthquake, which attended the eruption of it. This island was about three leagues in diameter, and nearly round; from whence it is manifest, that the quantity of pumice stones and melted matter, which must have been requisite to form it, was amazingly great:

\* See Philos. Transf. N° 409. or vol. vi. part ii. p. 201. Eames's Abr.

† See Philos. Transf. N° 209. or vol. ii. p. 418. Lowthorp's Abr.

‡ See Philos. Transf. N° 372. or vol. vi. part ii. p. 203. Eames's Abr.

in all probability, it must have far exceeded all that has been thrown out of *Ætna* and *Vesuvius* together within the last two thousand years. This may serve to satisfy us, that the fire which occasioned all this, must have subsisted for many years, not to say ages, and this without any communication with the external air. It is worth observing, that \* several instances of this kind have happened amongst the *Azores*. There are besides many marks of subterraneous fires about these islands, several places sending up smoke or flames. These islands are also subject to violent and frequent earthquakes.

30. We have more instances to the same purpose, near the island of *Santerini* in the *Archipelago*, where there have been several little islands raised out of the sea by a submarine volcano. The eruption of one of these in the year 1708, with all the circumstances that attended it, we have a very good account of in the † *Philosophical Transactions*. It was raised in a place where the sea had been formerly 100 fathoms deep, and was attended with earthquakes before it shewed itself above water, as well as after. It is reported, that the island of *Santerini* itself was originally raised out of the sea in the same manner; but, be that as it will, we have certain accounts of new islands raised there, or additions made to the old ones, from time to time, for above 1900 years backwards, and there have always been earthquakes at the time of these eruptions.

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\* See *Hist. and Philos. of Earthquakes*, under the titles *Azores*, *Islands raised*, &c.

† See N<sup>o</sup> 314, 317, and 332. or vol. v. part ii. p. 196. *Jones's Abr.*

31. Another example of the same kind happened at \* Manila, one of the Philippine islands, in the year 1750. This also was attended with violent earthquakes, to which that island, as well as the rest of the Philippines, is very much subject.

32. We may add to these, the many instances of vast quantities of † pumice stones, which have been sometimes found floating upon the sea, at so great a distance from the shore, as well as from any known volcano, that there can be little doubt of their being thrown up by fires subsisting under the bottom of the ocean.

33. From these instances, we may, with great probability, conclude, that the fires of volcanos produce earthquakes: I do not, however, suppose, that the earthquakes, which are frequently felt in the neighbourhood of volcanos, are owing to the fires of those volcanos themselves; for volcanos, giving passage to the vapours that are there formed, should rather prevent them, as in the instance at St. Christopher's, before-mentioned.

34. We also meet with frequent instances confirming the same thing amongst the Andes. Antonio d'Ulloa (speaking of what happens amongst these mountains) says, " Experience shews us, that, upon  
" the fresh breaking out of any volcano, it occasions  
" so violent a shock to the earth, that all the villages,  
" which are near it, are overthrown and destroyed,

\* See *Philos. Transf.* vol. xlix. p. 459.

† See *Philos. Transf.* N<sup>o</sup> 372. or vol. vi. part ii. p. 204. and N<sup>o</sup> 402. or vol. vii. part ii. p. 43. Eames's Abr.

“ as it happened in the case of the mountain \* Car-  
 “ guayrafo. This shock, which we may, without  
 “ the least impropriety, call an earthquake, is sel-  
 “ dom found to accompany the eruptions, after an  
 “ opening is once made; or, if some small trembling  
 “ is perceived, it is very inconsiderable; so that,  
 “ after the volcano has once found a vent, the shocks  
 “ cease, notwithstanding the matter of it continues  
 “ to be on fire.” The greater earthquakes, there-  
 fore, seem rather to be occasioned by other fires, that  
 lie deeper in the same tract of country; and the erup-  
 tions of volcanos, which happen at the same time  
 with earthquakes, may, with more probability, be  
 ascribed to those earthquakes, than the earthquakes  
 to the eruptions, whenever, at least, the earthquakes  
 are of any considerable extent. If this don’t appear  
 sufficiently manifest at present, it will, perhaps, be  
 better understood, by applying to the present pur-  
 pose, what will be said hereafter concerning local  
 earthquakes.

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\* It does not appear altogether certain, from the expression made use of in the French translation (from whence I have taken this), that Carguayrafo might not have been a volcano in former times, which is asserted to have been the case by Mons. Condamine. It is possible also, that the same may be true of those four mentioned in the next article; and, indeed, it is difficult to know it to be otherwise, in any instance, among the Andes, where the volcanos are generally found at inaccessible heights. But allowing, that all these were only old volcanos, which broke out afresh, yet they will serve at least to swell the number of them in the same neighbourhood, as well as to shew us, that there may, very probably, be many more, which lie hid: for these shewed no marks of their existence, till, by their eruption, they melted a vast quantity of snow, with which they were before covered, and which, being reduced to water, did great damage, by overflowing the country round about.



## S E C T. III.

35. It may be asked, perhaps, why we should suppose, that several subterraneous fires exist in the neighbourhood of volcanos? In evidence of this, we have frequent instances of new volcanos breaking out in the neighbourhood of old ones: Carguayraso, just mentioned, may supply us with one example to this purpose; and, in the night of the 28th of October 1746, in which Lima and Callao were destroyed, no less than four \* new ones burst forth in the adjacent mountains.

36. To the same purpose, we may allege the instances of many volcanos lying together in the same tract of country: as for example, the many places, “not so few as forty,” amongst the Azores, which either do now or have formerly sent forth smoke and flames; the many volcanos also amongst the Andes, already mentioned: thus *Ætna*, *Strombolo*, and *Vesuvius*, I may add *Solfatara* too, are all in the same neighbourhood: and *Monf. Condamine* says, he has traced † lavas, exactly like those of *Vesuvius*, all the way from *Florence* to *Naples*. In ‡ *Iceland* also, we have, besides *Hæcla*, not only several other volcanos, but also a great number of places, that send up sul-

\* See d’Ulloa’s *Voyage to Peru*, part ii. book i. chap. 7.

† See *Phil. Transf.* vol. xlix. p. 624. All these lavas, as well as the volcanos just mentioned, lie in a continued line. The same thing holds good in the volcanos of the Andes also. This is a fact I must desire the reader to attend to, as it serves to confirm a very material doctrine, which I shall have occasion to mention hereafter. See art. 44, 45, and 46.

‡ See *Horrebow’s Natural History of Iceland*.

phureous vapours. But the examples of this kind are so frequent, that there are few instances to be produced of single volcanos, without evident marks, either that there have been others formerly in their neighbourhood, or that there are, at present, subterraneous fires near them.

37. This frequency of subterraneous fires, in the neighbourhood of volcanos, will appear still more probable, if we consider the internal structure of the earth; and, as it will be necessary also, in order to understand what follows, to know a little more of this matter, than what falls under common observation, I shall endeavour to give the reader some account of it.

38. The earth then (as far as one can judge from the appearances), is not composed of heaps of matter casually thrown together, but of regular and uniform strata. These strata, though they frequently do not exceed a few feet, or perhaps a few inches, in thickness, yet often extend in length and breadth for many miles, and this without varying their thickness considerably. The same stratum also preserves a uniform character throughout, though the strata immediately next to each other are very often totally different. Thus, for instance, we shall have, perhaps, a stratum of potters clay; above that, a stratum of coal; then another stratum of some other kind of clay; next, a sharp grit sand stone; then clay again; next, perhaps, sand stone again; and coal again above that; and it frequently happens, that none of these exceed a few yards in thickness. There are, however, many instances, in which the same kind of matter is extended to the depth of some hundreds

hundreds of yards; but in all these, a very few only excepted, the whole of each is not one continued mass, but is again subdivided into a great number of thin laminæ, that seldom are more than one, two, or three feet thick, and frequently not so much.

39. Beside the horizontal division of the earth into strata, these strata are again divided and shattered by many perpendicular fissures, which are in some places few and narrow, but oftentimes many, and of considerable width. There are also many instances, where a particular stratum shall have almost no fissures at all, though the strata both above and below it are considerably broken: this happens frequently in clay, probably on account of the softness of it, which may have made it yield to the pressure of the superincumbent matter, and fill up those fissures which it originally had; for we sometimes meet with instances in mines, where the correspondent fissures in an upper and lower stratum are interrupted in an intermediate stratum composed of clay, or some such soft matter.

40. Though these fissures do sometimes correspond to one another in the upper and lower strata, yet this is not generally the case, at least not to any great distance: those clefts, however, in which the larger veins of the ores of metals are found, are an exception to this observation; for they sometimes pass through many strata, and those of different kinds, to unknown depths.

41. From this constitution of the earth, *viz.* the want of correspondence in the fissures of the upper and lower strata, as well as on account of those strata which are little or not at all shattered, it will come to pass,

pass, that the earth cannot easily be separated in a direction \* perpendicular to the horizon, if we take any considerable portion of it together; but in the horizontal direction, as there is little or no adhesion between one stratum and another, it may be separated without difficulty.

42. Those fissures which are at some depth below the surface of the earth, are generally found full of water; but all those that are below the level of the sea, must always be so, either from the oozing of the sea, or rather of the land waters between the strata.

43. The strata of the earth are frequently very much bent, being raised in some places, and depressed in others, and this sometimes with a very quick ascent or descent; but as these ascents and descents, in a great measure, compensate one another, if we take a large extent of country together, we may look upon the whole set of strata, as lying nearly horizontally. What is very remarkable, however, in their situation, is, that from most, if not all, large tracts of high and mountainous countries, the strata lie in a situation more inclined to the horizon, than the country itself, the † mountainous countries being generally,

\* What I said before of those deep clefts, in which metals are found, will not affect this conclusion; for they are considerably different from either perpendicular or plane sections of earth; they are frequently interrupted by strata of clay, or other soft matter; and they are, in most parts, either filled up with rubbish, or with ores and spars, that adhere as firmly to the rocks on both sides, as if they composed one continued stratum with them.

† It seems very probable, from many appearances, not only that the mountainous countries are formed out of the lower strata of the earth, but that sometimes the highest hills in them are formed out

Fig. 1.

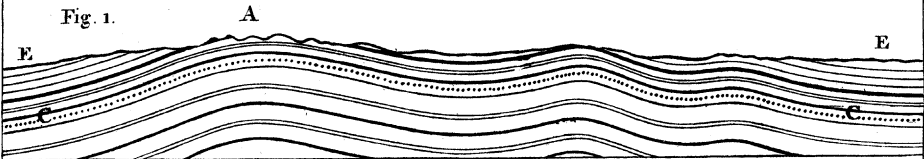


Fig. 3.

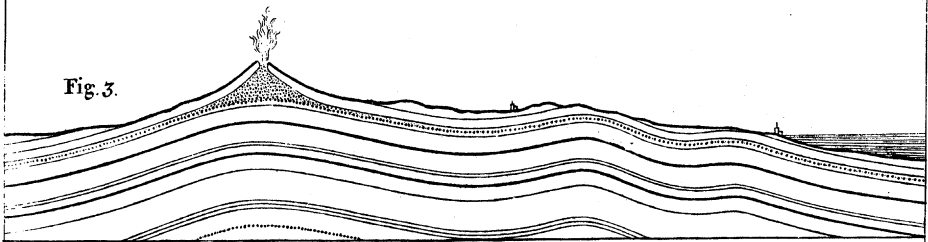


Fig. 4.

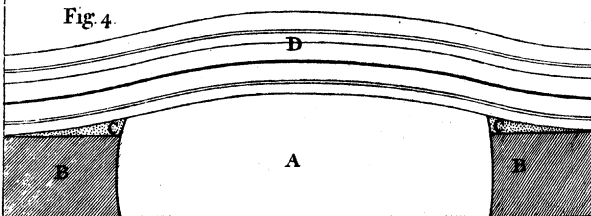
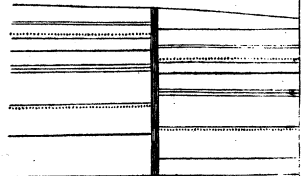


Fig. 2.



generally, if not always, formed out of the lower strata of earth. This situation of the strata may be not unaptly represented in the following manner. Let a number of leaves of paper, of several different sorts or colours, be pasted upon one another; then bending them up together into a ridge in the middle, conceive them to be reduced again to a level surface, by a plane so passing through them, as to cut off all the part that had been raised; let the middle now be again raised a little, and this will be a good general representation of most, if not of all, large tracts of mountainous countries, together with the parts adjacent, throughout the whole world \*.

44. From this formation of the earth, it will follow, that we ought to meet with the same kinds of earths, stones, and minerals, appearing at the surface, in long narrow slips, and lying parallel to the greatest rise of any long ridges of mountains; and so, in fact, we find them. The Andes in South America, as it has been said before, have a chain of volcanos, that extend in length above 5000 miles: these volcanos, in all probability, are all derived from the † same

out of strata still lower than the rest, which, perhaps, may always be the case, where they have volcanos in them. [See a representation of this in Tab. XIII. Fig. 3.] In other instances, however, it often happens, that the hills, to which these high lands serve as a base, are not only formed out of the strata next above them, but they stand, as it were, in a dish, as if they had depressed the ground, on which they rest, by their weight.

\* Fig. 1. represents a section of a sett of strata, lying in the situation just described: the section is supposed to be made at right angles to the length of the ridge, and perpendicular to the horizon.

† See the notes to art. 36 and 53. See also Fig. 3.

stratum.

stratum. Parallel to the Andes, is the Sierra, another long ridge of mountains, that run between the Andes and the sea; and “these two ridges of mountains run “within sight of one another, and almost equally, “for above a thousand leagues together \*,” being each, at a medium, about twenty leagues wide. The gold and silver mines wrought by the Spaniards, are found in a tract of country parallel to the direction of these, and extending through a great part of the length of them.

45. The same thing is found to obtain in North America also. The great lakes, which give rise to the river St. Laurence, are kept up by a long ridge of mountains, that run nearly parallel to the eastern coast. In descending from these towards the sea, the same sets † of strata, and in the same order, are generally met with throughout the greatest part of their length.

46. In Great Britain, we have another instance to the same purpose, where the direction of the ridge varies about a point from due north and south, lying nearly from ‡ N. by E. to S. by W. There are many more instances of this to be met with in the world, if we may judge from circumstances, which make it highly probable, that it obtains in a great number of places, and in several they seem to put it almost out of doubt.

47. The reader is not to suppose, however, that, in any instances, the highest rise of the ridge, and

\* See Acofta's Natural History of the Indies.

† See Lewis Evans's Map and Account of North America.

‡ Of this I could give many undoubted proofs, if it would not too far exceed the limits of my present design, and which, for that reason, I am obliged to omit.

the inclination of the strata from thence to the countries on each side, is perfectly uniform; for they have frequently very considerable inequalities, and these inequalities are sometimes so great, that the strata are bent for some small distance, even the contrary way from the general inclination of them. This often makes it difficult to trace the appearance I have been relating, which, without a general knowledge of the fossil bodies of a large tract of country, it is hardly possible to do.

48. At considerable distances from large ridges of mountains, the strata, for the most part, assume a situation nearly level; and as the mountainous countries are generally formed out of the lower strata, so the more level countries are generally formed out of the upper strata of the earth.

49. Hence it comes to pass, that, in countries of this kind, the same strata are found to extend themselves a great way, as well in breadth as in length: we have an instance of this in the chalky and flinty countries of England and France, which (excepting the interruption of the Channel, and the clays, sands, &c. of a few counties) compose a tract of about three hundred miles each way.

50. Besides the raising of the strata in a ridge, there is another very remarkable appearance in the structure of the earth, though a very common one; and this is what is usually called by miners, the trapping down of the strata; that is, the whole set of strata on one side a cleft are sunk down below the level of the corresponding strata on the other side. If, in some cases, this difference in the level of the strata, on the different sides of the cleft, should be



very considerable, it may have a great effect in producing some of the singularities of particular earthquakes \*.

## P A R T II.

51. **I**N the former part of this essay, I have recounted some of the principal appearances of earthquakes, as well as those particulars in the structure of the earth, upon which I suppose these appearances to depend. From what has been already said, I think it is sufficiently manifest, that, in some instances at least, earthquakes are actually produced by subterraneous fires; it now, therefore, remains to be shewn, how all the appearances above-recited, as well as many other minuter circumstances attending earthquakes, may be accounted for from the same cause.

### S E C T. I.

52. The returns of earthquakes in the same places, either at small or large intervals of time, are very consistent with the cause assigned: subterraneous fires, from their analogy to volcanos, might reasonably be supposed to subsist for many ages, though we had not those instances † already mentioned, which put the

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\* Fig. 2. represents a section of the strata trapping down after the manner just described. The section is supposed to be made perpendicularly to the horizon, and at right angles to the direction of the cleft: an instance of this kind, amongst the coal miners of Mendip in Somersetshire, is mentioned in the *Philos. Trans.* See the account of it, together with a drawing, in N<sup>o</sup> 360. or Jones's *Abr.* vol. iv. part ii. p. 260.

† See art. 28 to 32 inclusive.

matter out of doubt. And, as it frequently happens, that volcanos rage for a time, and then are quiet again for a number of years; so we see earthquakes also frequently repeated for some small time, and then ceasing again for a long term, excepting, perhaps, now and then some slight shock. And this analogy between earthquakes, and the effects of volcanos, is so great, that I think it cannot but appear striking to any one, who will read the accounts of both, and compare them together. The raging of volcanos is not one continued and uniform effect; but an effect, that is repeated at unequal intervals, and with unequal degrees of force: thus, for instance, we shall have, perhaps, two or three blasts discharged from a volcano, succeeding one another at the interval of a few seconds only: sometimes the intervals are of a quarter of an hour, an hour, a day, or perhaps several days. And as these intervals are very unequal, so is the violence of the blasts also: sometimes stones, &c. are thrown, by these blasts, to the distance of some miles; at other times, perhaps, not to the distance of a hundred yards. The same difference is observed in the intervals and violence of the shocks of earthquakes, which are repeated at small intervals for some time.

## S E C T. II.

53. The great frequency of earthquakes in the neighbourhood of burning mountains, is a strong argument of their proceeding from a cause of the same kind: and the analogy of several volcanos lying together in the same tract of country, as well as new ones breaking out in the neighbourhood of old ones,

tends greatly to confirm this opinion; but what makes it still the more probable, is that peculiarity in the structure of the earth, already mentioned. I observed before, that the same strata are generally very extensive, and that they commonly lie more inclining from the mountainous countries, than the countries themselves: these circumstances make it very probable, that those \* strata of combustible materials, which  
break

\* I has been imagined by some authors, that volcanos are produced by the pyrites of veins, and that they do not owe their origin to the matter of strata. In order to prove this, it is alleged, that volcanos are generally found on the tops of mountains, and that those are the places in which veins of pyrites are generally lodged. This argument being taken from observations that have their foundation in nature, ought not to go unanswered. In the first place, then, the pyrites of veins, or fissures, are not found in sufficient quantities, or extending to a sufficient breadth, to be supposed capable of producing the fires of volcanos: it very rarely happens, that we meet with a vein or fissure five or six yards wide; and when we meet with such an one, yet, perhaps, not a twentieth part of it at most shall be filled with pyrites; but the fires of volcanos, instead of being long and narrow, as if the matter that supplied them was deposited in veins, are generally round, and of far greater breadth than veins can be supposed to be. *Monf. Bouguer* says, that the mouth of the volcano *Cotopaxi* is, at this time, five or six hundred fathoms wide; [see *Hist. and Phil. of Earthquakes*, p. 195.] and the burning island that was raised out of the sea near *Tercera*, as before-mentioned, was almost three leagues in diameter, and nearly round. [See art. 29.]

Besides this, it is very difficult to conceive how any matters lodged in veins can ever take fire; for, excepting where the veins are extremely narrow, they are almost always drowned in a very great quantity of water, which has free access to every part of them: neither are the pyrites of veins, by any means, so apt to take fire of themselves, as those of strata; and if, indeed, there are any of them that will do so, yet they are but few in comparison of those which will not: all those, which, beside iron and sulphur, contain copper, or arsenic, even in a very small proportion, are not  
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break out in volcanos on the tops of the hills, are to be found at a considerable depth under ground in the level and low countries near them. If this should be the case,

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at all subject to inflame of themselves. On the other hand, most of the pyrites of strata, if not all of them, have this property more or less. There are also two sorts of strata, in which pyrites are lodged in the greatest abundance, that have the same property, and that frequently in as great a degree as themselves: these are coals and aluminous earths, or shale. There are some kinds of both these, that, upon being exposed to the external air for a few months, will take fire of themselves, and burn. These two sorts of strata are also near akin to each other; they are generally found to accompany each other; they are both of them generally intermixed with, or accompanied by strata of iron ore; and they both of them, for the most part, either contain, or are lodged amongst, the remains of vegetable bodies; and these remains of vegetable bodies, in the aluminous earths, are frequently either wholly, or in part, converted into pyrites, or coal, or both. Numberless instances of this are to be met with in the aluminous shale of Whitby and other places.

It is very probable, that to some stratum of this kind the fires of volcanos are owing; and this seems to be confirmed by the similarity of the materials, which are thrown up or sublimated by the fires of volcanos, to the matter of the aluminous earths. Solfatara produces sulphur, alum, and sal ammoniac. The two former of these are very easily to be obtained from the aluminous earths, and, I suppose, the latter also; at least it is procurable from the foot of common fossil coals, and probably, therefore, from the foot of that coaly matter which is intermixed with such earths.

The aluminous earths, moreover, not only have several strata of iron ore lying in them, but they also contain a considerable proportion of iron in their composition. In correspondence to this, we find the lavas of volcanos, and other matters thrown out from thence, frequently containing a great deal of iron, the small dust of them readily adhering to the magnet.

As to the pyrites of veins, I much doubt whether they ever contain alum, or sal ammoniac; at least they are very rarely found to contain either the one or the other.

and

and if the same \* strata should be on fire in any places under such countries, as well as on the tops of the hills, all vapours, of whatsoever kind, raised from these fires, must be pent up, unless so far as they can open themselves a passage between the strata; whereas the vapours raised from volcanos find a vent, and are discharged in blasts from the mouths of them. Now, if, when they find such a vent, they are yet capable of shaking the country to the distance of ten or twenty miles round, what may we not expect from them, when they are confined? We may form some idea of the force and quantity of these vapours from their effects: it is no uncommon thing to see them throw up, at once, such clouds of sand, ashes, and pumice stones, as are capable of darkening the whole air, and covering the neighbouring country with a shower of dust, &c. to some miles distance: great stones also, of some tons weight, are often thrown to the distance of two or three miles by these explosions: and Mons. Bouguer tells us, that he met with stones

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\* It may be asked, perhaps, why a stratum liable to take fire in some places, should not take fire throughout the whole extent of it? In answer to this, it may be said, that the same stratum may differ a little in the richness of its combustible principles in different places; or, perhaps, the frequency of the fissures, either in the combustible stratum itself, or the stratum next to it, may let in so much water, as to prevent its taking fire, excepting in a few places; but, if this once happens, the fire will not easily be put out again, but it will spread itself, notwithstanding the fissures that lie in its way, though they are filled with water; for the matter on fire will be, in some degree at least, in a fluid state; and, for this reason, it must necessarily expel the water from the fissures, both on account of the extension of its own dimensions by the heat, and of the weight of the superincumbent earth, which, pressing it, will make it spread laterally.

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in South America, of eight or nine feet diameter, that had been thrown from the volcano Cotopaxi, by one of these blasts, to the distance of more than \* three leagues.

54. If we suppose that these vapours, when pent up, are the cause of earthquakes, we must naturally expect, from what has been just said, that the most extensive earthquakes should take their rise from the level and low countries; but more especially from the sea, which is nothing else than waters covering such countries. Accordingly we find, that the great earthquake of the 1st November 1755, which was felt at places near three thousand miles distant from each other, took its rise from under the sea; this is manifest, from that wave which accompanied it, as shall be shewn hereafter. The same thing is to be understood of the earthquake that destroyed Lima in the year 1746, which, it has been said, was felt as far as Jamaica; and, as it was more violent than the Lisbon earthquake, so, if this be true, it must, in all probability, have been more extensive also. There have been many other very extensive earthquakes in South America: Acosta says, that they have been often known to extend themselves one, two, or three hundred, and some even five hundred leagues, along the coast. These have been generally, if not always, attended with waves from the sea; but any minuter

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\* See Hist. and Philos. of Earthq. p. 195. Don Antonio d'Ulloa, an author of great veracity, speaking of the same thing, says, that "the whole plain [near Latacunga] is full of large pieces of rocks, " some of them thrown from the volcano Cotopaxi, by one of its " eruptions, to the distance of five leagues." See his Voyage to Peru, part i. book vi. chap. 1.

circumstances accompanying them are not related. Indeed it is hardly to be expected that they should be observed, much less that they should be related, when they happened in a country so thinly inhabited, and where one may reasonably suppose, that, in general, only the grosser and more violent effects would be taken notice of.

### SECT. III.

55. I have said before, that I imagined earthquakes were caused by vapours raised from waters suddenly let out upon subterraneous fires. It is not easy to find any other cause capable of producing such sudden and violent effects, or of raising such an amazing quantity of vapour in so small a time. That the blasts, discharged from volcanos, are always produced from this cause, is highly probable; that they are often so, cannot admit of the least doubt. There can be no doubt, that considerable quantities of water must be often let out upon the fires of these volcanos, and whenever this happens, it will be immediately raised by the heat of them into a vapour, whose elastic force is capable of producing the most violent effects\*.

56. Both

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\* There are many effects produced by the vapour of water, when intensely heated, which make it probable, that the force of gunpowder is not near equal to it. The effects of an exceeding small quantity of water, upon which melted metals are accidentally poured, are such, as, I think, could in no wise be expected from the like quantity of gunpowder. Founders, if they are not careful, often experience these effects to their cost. An accident of this kind happened about forty years since, at the casting of two brass cannon at Windmill-hill, Moorfields. "The  
" heat

56. Both the tremulous and wave-like motion observed in earthquakes, may be very well accounted for

“ heat of the metal of the first gun drove so much damp into the  
 “ mould of the second, which was near it, that as soon as the  
 “ metal was let into it, it blew up with the greatest violence, tearing up the ground some feet deep, breaking down the furnace, untiling the house, killing many spectators on the spot, with the streams of melted metal, and scalding many others in a most miserable manner.” [See the note at the end of process 44th of the English translation of Cramer’s Art of assaying Metals.]

Other instances of the violence of vapours raised from water, are frequently to be met with: one of Papin’s digesters being placed between the bars of a grate, where there was a fire, was, after some time, burst by the violence of the steam, the fire was all blown out of the grate, and a piece of the digester was driven against the leaf of a strong oak table, which it broke to pieces. [See *Philos. Transf.* N° 454. or *Martyn’s Abr.* vol. viii. p. 465.] The marquis of Worcester also, in his *Century of Inventions*, tells us, that he burst a cannon by the same means.

It has been sometimes imagined, that the vapours, which occasion earthquakes, were of the same kind with those fulminating damps, of which we often meet with instances in coal mines. Now, there are several things which make it very probable, that this is not the case: it is true, the force of such vapours is very great; we have had instances, where large beams of timber have been thrown to the distance of an hundred yards by them: [see *Philos. Transf.* N° 136. or vol. ii. p. 381. *Lowthorp’s Abr.*] but what is this to the force of that vapour, which could throw stones of twenty or thirty ton weight to the distance of three leagues? Nor, indeed, is it at all probable, that any vapour, already in the form of a vapour, can, by suddenly taking fire, increase its dimensions so much, as to produce that immense quantity of motion, which we observe in some earthquakes: but this is rather to be expected from some solid body, such as water, which is capable of being converted, and that almost instantly, into one of the lightest, and perhaps one of the most elastic, vapours in the world. Air, when heated to the greatest degree that it is capable of receiving from the hottest fires we can make, acquires a degree of elasticity about five times as great as that of common air: the vapour of



for from such a vapour. In order to trace a little more particularly the manner in which these two motions

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gunpowder, whilst it is inflamed, has also about five times the elastic force which it has when cold. [See Robins's excellent tract on Gunnery.] Now, if we suppose a fulminating damp, of any kind, to increase its elasticity, when inflamed in the same proportion, this will be abundantly sufficient to make it produce any effects, which we have ever seen produced by any of the damps of mines, &c. And, indeed, whoever carefully examines the effects, either of the damps of mines, or of those fulminating damps, that are raised from some metals, when in fusion, or when they are dissolving in acids, will rather be inclined to think, that the force of inflamed vapours is so far from exceeding the proportion of five to one, that it falls considerably short of it.

But though we should suppose that this proportion holds good, where shall we find a place capable of containing a sufficient quantity of such a vapour, to produce the great effects of earthquakes? It will be said, perhaps, in subterraneous caverns. To this we may answer, that he, who is but moderately acquainted with the structure of the earth, and the materials of which it is composed, will be little inclined to allow of any great or extensive caverns in it. But, though this should be admitted, how can it come to pass that these caverns should not be filled with water? If it is alleged, that the water is expelled, as the vapour is formed, why should not the vapour, as it is supposed to be the lighter, be expelled, rather than the water, by the same passages by which the water is to be expelled? But let us suppose this difficulty also to be got over, and the water to be removed, and we shall then have a gage for the density of the vapour; for it must be just sufficient to make it capable of sustaining a column of water, whose height is equal to that of the surface of the sea above the bottom of the cavern, in which the vapour is supposed to be contained. Now, since the mean weight of earth, stones, &c. is not less than two and a half times the weight of water, this vapour must be increased to two and half times its original elasticity, before it can, in any wise, raise the earth above it; and if we suppose it to be increased to five times its original elasticity, it will then be no more than twice able to do so; in which case, so much vapour only can be discharged from the cavern, to produce an earthquake, as is equal to the  
content

motions will be brought about, let us suppose the roof over some subterraneous fire to fall in. If this should be the case, the earth, stones, &c. of which it was composed, would immediately sink in the melted matter of the fire below : hence all the water contained in the fissures and cavities of the part falling in, would come in contact with the fire, and be almost instantly raised into vapour. From the first effort of this vapour, a cavity would be formed (between the melted matter and superincumbent earth) filled with vapour only, before any motion would be perceived at the surface of the earth : this must necessarily happen, on account of the \* compressibility of

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content of the cavern : and what must the size of that cavern be, which could contain vapour enough to produce the earthquake of the 1st of November 1755, in which an extent of earth of near three thousand miles diameter was considerably moved ? or how can we suppose, that the roof of such a cavern, when so violently shaken, should avoid falling in ? especially, as it is hardly to be supposed, that any inflamed vapour whatsoever should be able to move the earth over these caverns, if they lay at any great depth, since the weight of less than three miles depth of earth is capable of retaining the inflamed vapour of gunpowder within the original dimensions of the gunpowder itself ; and common air, compressed by the same weight (supposing the known law of its compression to hold so far), would be of greater density than water.

We may ask still farther, whence such vast quantities of vapour should be formed, or what sources they must be, which would not be exhausted (if they were not again replenished) by a very few repetitions of such immense discharges.

\* The compressibility and elasticity of the earth, are qualities which don't show themselves in any great degree in common instances, and therefore are not commonly attended to. On this account it is, that few people are aware of the great extent of them, or the effects that may arise from them, where exceeding large quantities of matter are concerned, and where the compressibility

of all kinds of earth, stones, &c. but as the compression of the materials immediately over the cavity, would

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five force is immensely great. The compressibility and elasticity of the earth may be collected, in some measure, from the vibration of the walls of houses, occasioned by the passing of carriages in the streets next to them. Another instance to the same purpose, may be taken from the vibrations of steeples, occasioned by the ringing of bells, or by gusts of wind: not only spires are moved very considerably by this means, but even strong towers will, sometimes, be made to vibrate several inches, without any disjoining of the mortar, or rubbing of the stones against one another. Now, it is manifest, that this could not happen, without a considerable degree of compressibility and elasticity in the materials, of which they are composed: and if such small things as the weight of steeples, and the motion of bells in them, or a gust of wind, are capable of producing such effects, what may we not expect from the weight of great depths of earth? There are some circumstances, which seem to make it not altogether improbable, that the form and internal structure of the earth depend, in a great measure, upon the compressibility and elasticity of it. There are several things that seem to argue a considerably greater density in the internal, than the external part of the earth; and why may not this greater density be owing to the compression of the internal parts arising from the weight of the superincumbent matter, since it is probable, that the matter, of which the earth is composed, is pretty much of the same kind throughout? There is a still stronger argument for the earth's owing its form, in some measure, to the same cause; for it is found to be higher [see the French accounts of the measures of a degree of the meridian in France, Sweden, and America] at the æquator, than at the poles, in a greater proportion than it would be on account of the centrifugal force, if it was of uniform density; but, if we suppose the earth to be of less density in an æquatorial diameter than in the axis, the whole will then be easily accounted for, from the rising of the earth a little by its elasticity, the weight being in part taken off by the diurnal rotation: and that the earth is really a little denser in the axis, than in the æquatorial diameter, seems highly probable, from the experiments of pendulums compared with astronomical observations; for the forms of the earth derived from these, cannot be reconciled

would be more than sufficient to make them bear the weight of the superincumbent matter, this compression must be propagated on account of the elasticity of the earth, in the same manner as a pulse is propagated through the air; and again the materials immediately over the cavity, restoring themselves beyond their natural bounds, a dilatation will succeed to the compression; and these two following each other alternately, for some time, a vibratory motion will be produced at the surface of the earth. If these alternate dilatations and compressions should succeed one another at very small intervals, they would excite a like motion in the air, and thereby occasion a considerable noise. The noise that is usually observed to precede or accompany earthquakes, is probably owing partly to this cause, and partly to the grating of the parts of the earth together, occasioned by that wave-like motion before-mentioned.

57. After the water, that first came in contact with the fire, has formed a cavity, all the rest of the water contained in the fissures, immediately communicating with the hollow left by the part that fell in,

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reconciled with each other, but upon this supposition. [See Mac-laurin's Fluxions, art. 681, &c.] It appears, from some late and accurate observations, that the æquatorial parts of the planet Jupiter also, as well as those of the earth, are a little higher than they would be, if their rise was owing to the centrifugal force, and he was of uniform density; but if we suppose him to be of less density in the æquatorial, than the polar regions, then the form may be such as he would assume from the respective gravitation of the several parts; and any fluid like our ocean, would not overflow the polar parts, (which, upon any other supposition, it must necessarily do) but would follow his general form, as our ocean does that of the earth.

must run out upon the fire, the steam taking its place. From hence may be generated a vast quantity of vapour, the effects of which shall be considered presently. This steam will continue to be generated, supposing the fire to be sufficiently great, till the fissures before-mentioned are evacuated, or till the water begins to flow very slowly; when the steam already formed will be removed by the elasticity of the earth, which will again subside, and, pressing upon the surface of the melted matter, will force it up a little way into all the clefts, by which the water might continue to flow out. By this means, all communication between the fire and the water will be prevented, excepting at these clefts, where the water, dripping slowly upon the melted matter, will gradually form a crust upon it, that will soon stop all farther communication in these places likewise; and the fissures, that had been before evacuated, will be again gradually replenished by the oozing of the water between the strata.

58. As a small quantity of vapour almost instantly generated at some considerable depth below the surface of the earth, will produce a vibratory motion, so a very large quantity (whether it be generated almost instantly, or in any small portion of time) will produce a wave-like motion. The manner in which this wave-like motion will be propagated, may, in some measure, be represented by the following experiment. Suppose a large cloth, or carpet, (spread upon a floor) to be raised at one edge, and then suddenly brought down again to the floor, the air under it, being by this means propelled, will pass along, till it escapes at the opposite side, raising the cloth

cloth in a wave all the way as it goes. In like manner, a large quantity of vapour may be conceived to raise the earth in a wave, as it passes along between the strata, which it may easily separate in an horizontal direction, there being, as I have said before, little or no cohesion between one stratum and another. The part of the earth that is first raised, being bent from its natural form, will endeavour to restore itself by its elasticity, and the parts next to it beginning to have their weight supported by the vapour, which will insinuate itself under them, will be raised in their turn, till it either finds some vent, or is again condensed by the cold into water, and by that means prevented from proceeding any farther.

59. If a large quantity of vapour should continue to be generated for some time, several waves might be produced by it; and this would be, in some measure, the case, if the quantity at first generated was exceedingly great, though the whole of it was generated in less time, than whilst the motion was propagated through the distance between two waves.

60. These waves must rise the higher, the nearer they are to the place from whence they have their source; but, at great distances from thence, they may rise so little, and so slowly, as not to be perceived, but by the motions of waters, hanging branches in churches, &c.

61. The vibratory motion occasioned by the first impulse of the vapour, will be propagated through the solid parts of the earth, and therefore, it will much sooner become too weak to be perceived, than the wave-like motion; for this latter, being occasioned by the vapour insinuating itself between the strata,

strata, may be propagated to very great distances; and even after it has ceased to be perceived by the the senses, it may still discover itself by the appearances before-mentioned.

#### S E C T. IV.

62. All earthquakes derived from the same subterraneous fire, must come to the same place in the same direction; and those only which are derived from different fires, will come from different points of the compass; but as, in all probability, it seldom happens that earthquakes, caused by different fires, affect the same place, we therefore find in general, that they come from the same quarter: it is not, however, to be supposed, that this should always be the case, for it will, probably, sometimes happen to be otherwise: and this is to be expected in such places as are situated in the neighbourhood of several subterraneous fires; or where, being subject to the shocks of some local earthquake of small extent, they now and then are affected by an earthquake, produced by some more distant, but much more considerable cause. Of this last case, we seem to have had some instances in the earthquake of the 1st of November 1755, and those local ones, before-mentioned, which succeeded it.

63. As we may reasonably infer from many earthquakes coming to the same place, from the same point of the compass, that they are all derived from the same cause, and that a permanent one; so we may reasonably infer the same thing also, from their being propagated with the same velocity; but this argument will still come with the greater force, if it be considered,

considered, that the velocity of any vapour, which insinuates itself between the strata of the earth, depends upon the depth of it below the surface; for the deeper it lies, the greater will be its \* velocity. We may therefore conclude, from the sameness of the velocity of the earthquakes of the same place, that the cause of them lies at the same depth; and from the inequality of the velocity of the earthquakes of different places, that their causes lie at different depths. Both these are perfectly consistent with the supposition, that earthquakes owe their origin to subterraneous fires, since the strata in which these subsist, may be easily conceived to lie at different depths in different parts of the world.

## S E C T. V.

64. From the same cause, we may easily account for those local earthquakes, which succeed the greater and more extensive ones. If there are many subterraneous fires subsisting in different parts of the world, the vapour coming from one fire may very well be supposed, as it passes, to disturb the roof over some other fire, and, by that means, occasion earthquakes by the falling in of some part of it: and this may be the case, in some measure, even where the vapour passes at some small distance over the fire; but it will be most likely to take place, where the vapour either

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\* The velocity of such a vapour, depending intirely upon the elasticity of the earth which is over it, will be, *cæteris paribus*, (if I am not mistaken) in the ratio of the depth below the surface. This seems to follow from a known law of all elastic bodies, according to which they tend to return to their state of rest, when either dilated or compressed, with forces proportionable to the quantity by which they differ from their natural bounds.



passes at some distance under it, or between the stratum, in which the fire lies, and that next above or below it.

## P A R T III.

### S E C T. I.

65. **I**N the former part of this tract, I supposed a part of the roof over some subterraneous fire to fall in: this is an event that cannot happen merely accidentally; for so long as the roof rests on the matter on fire, no part of it can fall in, unless the matter below could rise and take its place: now, it is very difficult to conceive how this should happen, unless it was to rise by some larger passages than the ordinary fissures of the earth, which seem much too narrow for that purpose; for, besides that the melted matter cannot be supposed to have any very great degree of fluidity, it must necessarily have a hard crust formed upon it, at all the fissures, by the long continued contact of the water contained in them: these impediments seem too great to be overcome by the difference of the specific gravities of the part that is to fall in, and the melted matter, which is the only cause that can tend to make it descend; the manner therefore, in which, I suppose, this event may be brought about, is as follows:

66. The matter of which any subterraneous fire is composed, must be greatly \* extended beyond its original

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\* As all bodies we are acquainted with are liable to be extended by heat, there can be no doubt of its being so in this case likewise;

ginal dimensions by the heat. As this will be brought about gradually, whilst the matter spreads itself, or grows hotter, the parts over the fire will be gradually raised and bent; and this bending will, for some time, go on without any other consequence; but, as the fire continues to increase, the earth will at last begin to be raised somewhat beyond the limits of it. By this means, an annular space will be formed at the edges next to the fire, and surrounding it, a vertical section of which space, through a diameter of the fire, will be two long triangles, the shortest side or base of each lying next the fire, and the two longer sides being formed by the upper and lower strata, which will be separated for a considerable extent, proportionably to the distance through which they are raised from each other \*. This space will be gradually

likewise; but the matter of subterraneous fires is yet much more extended, than those bodies which are only capable of being melted into a solid glass, if we may judge of it from what we see of volcanos; for the lavas, scoriæ, and pumice stones, thrown out from thence, even after they are cold, are commonly of much less specific gravity, on account of their porous spongy texture, than the generality of earth, stones, &c. and they frequently are even lighter than water, which is itself lighter than any known fossil bodies, that compose strata in their natural state.

\* In Fig. 4. A is supposed to represent a vertical section of the matter on fire; BB, parts of the same stratum yet unkindled; CC, the two sections of the annular space, (surrounding the fire) which is supposed to be filled with water, as far as the strata are separated; D, the several sets of earth, stones, &c. lying over the fire, which are raised a little, and bent, by the expansion of the matter at A. As it is not easy to represent the things above described in their due proportions, it may not be amiss, in order to prevent the figure here given from misleading the reader, to give some random measures of the several parts, such as may probably

gradually filled with water, as it is formed, the melted matter being prevented from filling it, by its want of fluidity, as well as on account of the other circumstances, under which it is to spread itself; for the lentor and sluggishness of this kind of matter is such, that, when somewhat cooled on the surface by the contact of the air only, it will not flow, perhaps, ten feet in a month, though in a very large body; instances of which we have in the lavas of *Ætna*, *Vesuvius*, &c. It is not to be expected then, that it should spread far, when it comes in contact with water at its edges, as soon as it is formed, and when it is, perhaps, several months in acquiring a thickness of a few inches; but it must, by degrees, form a kind of wall between the fire and the opening into the annular space before described. This wall will gradually increase in height, till it becomes too tall in proportion to its thickness, to bear any longer the pressure of the melted matter; which

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approach towards those which are sometimes found in nature: we may suppose then the stratum B to be, perhaps, from ten or twenty to a hundred yards in thickness; the greatest height of the annular space C, next the fire, to be from four or five to ten or fifteen feet, and its greatest extent, horizontally, from ten or twenty to fifty or sixty feet; the horizontal extent of the fire at A, may be from half a mile to ten or twenty miles; [See art. 29. and the note to art. 53.] and the thickness of the superincumbent matter at D, may be from a quarter or half a mile to two or three miles; the number of the laminæ also, into which it is divided, may be many times more than those in the figure. As to the perpendicular fissures, they must be so numerous, and so small, in proportion to the other parts, that I chose rather to leave them, to be supplied by the imagination of the reader, than attempt to express them in a manner, that could give no adequate idea of them at all.

must

must necessarily happen at last, because the thickness of it will not exceed a certain \* limit.

67. Besides the giving way of this wall, the fire may undermine the space containing the water, and, by that means, open a communication between them. Let us suppose one of these come to pass, and the time arrived when the partition begins to yield. If then the water had any way to escape readily, the breach would be made, and the melted matter would burst forth immediately, and flow out in large quantities at once amongst it; but as this is not the case, and it can only escape by oozing slowly between the strata, and through the fissures, the way that it came, the breach will be made gradually, from whence we may account for some appearances that have preceded great earthquakes.

68. We are told, that two or three days before an † earthquake in New England, the waters of some wells were rendered muddy, and stank intolerably :

\* This limit will depend upon the thickness of the matter necessary to prevent so quick a communication of the heat or cold through it, as that the water should be able to diminish the heat of the fire considerably. The thickness requisite to do this, is very different in different kinds of bodies. Metals of all kinds transmit heat and cold extremely readily; but bricks and vitrified substances (with which last we may class the matter under our present consideration) transmit them very slowly: the walls of the hottest of our furnaces, when built of bricks, and eighteen inches thick, will not transmit more heat than a living animal can bear without injury, though the fires are continued in them for ever so long a time; probably, therefore, if we allow two feet for the thickness of the matter, cooled and rendered hard by the contact of the water, we shall not underdo it.

† See *Philos. Trans.* N° 437. or *Martyn's Abridgm.* vol. viii. p. 689.

why

why might not this be occasioned by the waters contained in the spaces before described, which, being impregnated with sulphureous steams, were driven up, and mixed with the waters of the springs? At least, there can be no doubt, by whatsoever means it was brought about, that this phænomenon was owing to the same cause, already beginning to exert itself, which afterwards gave rise to the succeeding earthquake.

69. Something like this happened before the great Lisbon \* earthquake of 1755. We are told, that at Colares, about twenty miles from thence, “ in the afternoon preceding the 1st of November, the water of a fountain was greatly decreased: on the morning of the 1st of November, it ran very muddy, and after the earthquake, it returned to its usual state, both in quantity and clearness.” The same author says, a little lower, “ in the afternoon of the 24th, I was much apprehensive, that the following days we should have another great earthquake; for I observed the same prognostics as in the afternoon of the 31st October; that is,” &c. “ And I farther observed, that the water of a fountain began to be disturbed to such a degree, that in the night it ran of a yellow clay colour; and from midnight to the morning of the 25th, I felt five shocks, one of which seemed to me as violent as that of the 11th of December.”

70. But the most extraordinary appearance of any that preceded this earthquake, was that of the agita-

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\* See Philos. Trans. vol. xlix, p. 416 and 417.—or Hist. and Philos. of Earthq. p. 313.

tion of the waters of \* Lochness, and some others of the lochs in Scotland, about half an hour before any motion was felt at Lisbon, notwithstanding the cause of all these great effects could not lie far from thence, and, I think, certainly lay to the south of Oporto. Nor is it probable, that there should be any mistake in the time, not only because the difference is too great, as well as the concurrent testimonies too many, to admit of such a solution; but because they mention another greater agitation, that happened about an hour and half after the former; which latter agrees with the times, when the agitations of the waters were observed in England, if we allow only a proper interval for the motion to be propagated so far northward, proportionably to the time it took up in travelling from its original source near Lisbon.

71. These appearances seem to be connected with that mentioned in the preceding article, and they may both, I think, be accounted for, by supposing a considerable quantity of vapour to be raised, whilst the partition before-mentioned was beginning to give way; during which time, a partial

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\* See *Philos. Trans.* vol. xlix.—or *Hist. and Philos. of Earthq.* art. Lochness, Lochlommond, &c. The same thing also seems to have taken place in Switzerland; for *Mons. Bertrand* says, that all the agitations of the waters in the lakes there, which were observed on the 1st November 1755, happened between nine and ten in the morning; and particularly at lake Lemane, he says, the agitation happened just before ten; which, allowing for the difference of longitude, must have been just before nine at Lisbon; and, consequently, if there is no mistake in the times, all these agitations preceded the earthquake, at this last place, by near three quarters of an hour. [See *Memoires sur les tremblemens de Terre*, p. 107 et. 105.]

communication between the water and fire would be brought on, and that by degrees only. Hence the vapour, not being produced at once but gradually, might creep \* silently between the strata, towards that quarter where the superincumbent mass of earth was lightest; and, by this means, some places very near the source of the vapour might be little, or not at all, affected by it, whilst others might be greatly affected, though they lay at a great distance; and even those places, which lay immediately over the part where the vapour was passing, might not perceive any effect, on account of the gentleness of the motion, occasioned by the small quantity of it. This might continue to be the case, till it came to some country where, the set of strata above being much thinner, the vapour would not only be hurried forward, but collected also into a much narrower compass; and therefore, raising the earth more, would produce more sensible effects; and this we ought

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\* Some appearances that have been observed in New England seem to confirm this, and make it probable, that a small quantity of vapour is often found to creep silently between the strata, before a general communication between the water and the fire gives rise to the greater and more sensible effects of earthquakes. See *Philos. Trans.* N° 462. or *Martyn's Abr.* vol. viii. p. 693. where we are told, that, at Newbury, a little before any noise or shock was perceived, the bricks of an hearth were observed to rise, and, falling down again, to lean another way. In the same account, it is also said, that “ a few minutes before any shock came, many people “ could foretell it by an alteration in their stomachs:” an effect, which seems to be of the same kind with sea-sickness, and which always accompanies the wave-like motion of earthquakes, when it is so weak, as to be uncertainly distinguishable.

chiefly

chiefly to expect in the most mountainous countries, according to the idea before given of them \*.

72. To make this something clearer, let us suppose, in Fig. 1. the vapour to be passing between the strata in the dotted line C, and to go forwards, till it arrives at A : whilst, then, it passes under the deeper parts at E, it will raise the earth over it but little, as well because it will be spread broader and thinner, as because it will be more compressed by the weight of the superincumbent matter ; but as it arrives towards A, not only the latter part will be driven forwards with greater velocity, but the foremost will travel slower, on account of its travelling under a † thinner set of strata ; and, besides this, the load being much less, it will greatly expand itself. From all these causes taken together, the wave at the surface of the earth, occasioned by the passing of the vapour under it, will not only be much higher, but also much shorter, and, consequently, the sides of it, on both these accounts, will be much more inclined to the horizon : and, moreover, because the progress of the wave will be slower, it will give more time to any waters situated on one side of it, to flow one way ; and on this account also, the apparent agitation of them will be increased.

## SECT. II.

73. We are told, that, in the Lisbon earthquake of 1755, “ the bar [at the mouth of the Tagus] was “ seen dry from shore to shore ; then suddenly the sea,

\* See art. 43.

† See art. 63. the note.



“ like a mountain, came rolling in ; and about Bel-  
 “ lem castle, the water rose fifty feet almost in an  
 “ instant ; and, had it not been for the great bay  
 “ opposite to the city, which received and spread  
 “ the great flux, the low part of it must have been  
 “ under water \*.” The same phænomena were ob-  
 served to accompany the same earthquake at the island  
 of Madeira ; where we are told, that, at the city of  
 Funchal, “ the sea, which was quite calm, was ob-  
 “ served to retire suddenly some paces ; then rising  
 “ with a great swell, without the least noise, and as  
 “ suddenly advancing, it overflowed the shore, and  
 “ entered the city. It rose full fifteen feet perpen-  
 “ dicular above high-water mark, although the tide,  
 “ which ebbs and flows there seven feet, was then  
 “ at half ebb. In the northern part of the island,  
 “ the inundation was more violent, the sea retiring  
 “ there above one hundred paces at first, and sud-  
 “ denly returning, overflowed the shore, forcing  
 “ open doors, breaking down the walls of several  
 “ magazines and storehouses, and carrying away, in  
 “ its recess, a considerable quantity of grain, and  
 “ some hundred pipes of wine †.”

74. Both these appearances (which have been observed to attend several other earthquakes, as well as this) seem to admit of an easy solution, supposing the cause of them to lie under the bed of the ocean ; for, in the farther progress of the communication between the fire and water, the vapour, that is

\* See Hist. and Philos. of Earthq. p. 316.

† See Philos. Trans. vol. xlix. p. 432, &c.—or Hist. and Philos. of Earthq. p. 329.

gradually raised at first, will at last begin to raise the roof over the fire, which, being supported by so light a vapour, there will now be no want of fluidity in the matter it rests upon, and the difference of specific gravity between the two, instead of being small, will be very great: hence, if any part of the roof gives way, it must immediately fall in, the vapour readily rising, and taking its place; and a beginning being once made, a communication will be opened with numberless clefts and fissures, that must occasion the falling in of vast quantities of matter, which, as soon as the vapour can pass round them, will want their support; then will follow the great \* effects already described.

75. Now, whilst the roof is raising, the waters of the ocean, lying over it, must retreat, and flow from thence every way; this, however, being brought about slowly, they will have time to retreat so gently, as to occasion no great disturbance: but as soon as some part of the roof falls in, the cold water contained in the fissures of it, mixing with the steam, will immediately produce a vacuum, in the same manner as the water injected into the cylinder of a steam engine, and the earth subsiding, and leaving a hollow place above, the waters will flow every way towards it, and cause a retreat of the sea on all the shores round about: then presently, the waters being again converted by the contact of the fire into vapour, together with all the additional quantity, which has now an open communication with it, the earth will be raised, and the waters over it will be made to flow every

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\* See art. 56 to 60 inclusive.

way, and produce a great wave immediately succeeding the previous retreat \*.

### S E C T. III.

76. That great quantity of water, which we have supposed to be let out upon subterraneous fires, and, by that means, to produce earthquakes, will supply us with a reason, why they observe a sort of periodical return. This water must extinguish a great portion of the burning matter, in consequence of which, it will be contracted within much narrower bounds; and though the effects before described could not take place at first, but by the great extension of the heated matter, yet, after they have once taken place,

\* It may, perhaps, be objected, that these phænomena may as easily be occasioned by a vapour generated under the dry land, which, by first raising the earth upon the sea-shore, would make the waters retreat; and that the return of them again, upon its subsiding into its place, might cause the subsequent wave. That this may be the case, in some instances, is not impossible, but, I believe, upon examining the particular circumstances, it will generally be found to be otherwise; and there cannot be any doubt about it, in the case of the Lisbon earthquake; for the retreat was observed to precede the wave, not only on the coast of Portugal, but also at the island of Madeira, and several other places: now, if the retreat had been caused by the raising of the earth on the coast of Portugal, the motion of the waters occasioned by this means, when propagated to Madeira, must have produced a wave there previous to the retreat, contrary to what happened; nor could the motion of the waters at Madeira be caused by the earthquake at that place, because it did not happen till above two hours after; whence it is manifest, that it must have been owing to the continuation of a motion propagated from the place, where the earthquake exerted its first efforts. And we may observe, in general, that this must always be the case, whenever the retreat does not happen till some considerable time after the earthquake.

they

they may well continue to do so for some time; for the great disturbance in the first instance, by the falling in of a great part of the roof, must render the frequent communication between the fire and water not only very easy, but almost unavoidable: and this will continue to be so, till the roof is well settled, and the surface of the melted matter sufficiently cooled, after which, it may require a long time for the fire to heat it again so much, as will be necessary to make it produce the former effects. Now, as the matter has been more or less cooled, or as the combustible materials are with more or less difficulty set on fire again, as well as on account of other circumstances, the returns of these effects will be later or earlier; but though they will not, for this reason, observe any exact period, yet they will generally fall within some sort of limits, till either the matter that occasions them is consumed, (which, probably, will seldom happen in less than many ages) or till the fires open themselves a passage, and become volcanos.

#### S E C T. IV.

77. I have already intimated, that the most extensive earthquakes frequently take their rise from the sea. According to the description of the \* structure of the earth before given, any combustible stratum must lie at greater depths in places under the ocean, than elsewhere; hence far more extensive fires may subsist there, than where the quantity of matter over them is less; for any vapour raised from such fires,

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\* See art. 43.

having both a stronger roof over it, and being pressed by a greater weight, (beside the additional weight of the water) will not only be less at liberty to expand itself, and consequently of less bulk, but it will also be easily driven away towards the parts round about, where the superincumbent matter is less, and therefore lighter. On the other hand, any vapour raised from fires, where the superincumbent matter is lighter, finding a weaker roof over it, and being not so easily driven away under strata, that are thicker and heavier, will be very apt to break through, and open a mouth to a volcano; and it must necessarily do this long before the fires can have spread themselves sufficiently, to be near equal to those which may subsist in places that lie deeper. All this seems to be greatly confirmed by the situation of volcanos, which are almost always found on the \* tops of mountains, and those often some of the highest in the world.

78. If, then, the largest fires are to be supposed to subsist under the ocean, it is no wonder that the

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\* Perhaps this may supply us with a hint (if the conjecture is not thought extravagant) concerning the manner in which these mountains have been raised, and why the strata lie generally more inclining from the mountainous countries, than those countries themselves; an appearance not easily to be accounted for, but upon the supposition, that the upper parts of the earth rest upon matter, in some degree, though not perfectly fluid, and that this matter is lighter than the earth that rests upon it. This conjecture, however, will probably be thought less strange, if it be considered, that the new islands, formed about Santerini and the Azores, have some of them been raised from 200 to 300 yards, and upwards; a height which might well enough intitle them to the denomination of mountains, if they had been raised from lands not lying under the ocean. [See Fig. 3.]

most extensive earthquakes should take their rise from thence: the great earthquake of Lisbon has been \* shewn to have done so; and that the cause of it was also at a greater depth, than that of many others, appears from the greater † velocity with which it was propagated.

79. The great earthquake that destroyed Lima and Callao in 1746, seems also to have come from the sea; for several of the ports upon the coast were overwhelmed by a great wave, which did not arrive till four or five minutes after the earthquake began, and which was preceded by a ‡ retreat of the waters, as well as that at Lisbon. Against this, it may, perhaps, be alleged, that there were four || volcanos broke out suddenly, in the neighbouring mountains, when this earthquake happened, and that the fires of these might be the occasion of it. This however, I think, is not very probable; for, to omit the argument of the wave, and previous retreat of the waters, already mentioned, it is not very likely, that more than one fire was concerned: besides, the vapour, opening itself a passage at these places, could not well be supposed, if it took its rise from thence, to spread itself far; especially towards the sea, where it is manifest,

\* See art. 54. See also art. 94 to 97 inclusive.

† See the note to art. 63.

‡ Both the wave and previous retreat have been observed in the other great earthquakes, which have happened at Lima, and in the neighbouring country. See d'Ulloa's *Voyage to Peru*, part ii. book i. chap. 7.

|| If these volcanos were not new ones, but only old ones which broke out afresh, [See the note to art. 34.] the argument will come with still greater force.

that the strata over it were of great thickness, as appears from the great velocity with which the earthquake was propagated there: the shocks also continued with equal, or nearly equal violence, for some months after the openings were made; whereas, if these fires had been the cause of them, they must immediately have ceased, upon the fires finding a vent, as it has happened in other \* cases. It is therefore much more probable, that a very large quantity of vapour, taking its rise from some far more extensive fire under the sea, spread itself from thence; and as it passed in places, where the roof over it was naturally much thinner, as well as greatly weakened by the undermining of these fires, it opened itself a passage, and burst forth.

80. As the most extensive earthquakes generally proceed from the lowest countries, but especially from the sea, so those of a smaller extent are generally found amongst the mountains: hence it almost always happens, that earthquakes, which are felt near the sea, if at all violent, are felt also in the higher lands; whereas there are many amongst the hills, and those very violent ones, which never extend themselves to the lower countries. Thus we are told, that, at Jamaica, “ † shakes often happen in “ the country, not felt at Port-Royal; and some- “ times are felt by those that live in and at the foot

\* See art. 28.

† This is taken from an account of the earthquake that happened at Jamaica in the year 1692, which, as well as some others before-mentioned, was attended with the wave and previous retreat. See *Philos. Transf.* N° 209. or *Lowthorp's Abr.* vol. ii. p. 417 and 418.

“ of the mountains, and by no body else.” On the other hand, the earthquake that destroyed Port-Royal extended itself all over the island: and the same was observed of a smaller earthquake, that happened there in 1687-8; which latter undoubtedly came from the sea, as appears by Sir \* Hans Sloane’s account of it.

81. Earthquakes of small extent are also very common amongst the mountains of Peru and Chili. Antonio d’Ulloa says, “ Whilst we were preparing for  
“ our departure from the mountain Chichi-Choco,  
“ there was an earthquake which was felt four  
“ leagues round about: our field tent was tossed to  
“ and fro by it, and the earth had a motion like  
“ that of waves; this earthquake, however, was  
“ one of the smallest, that commonly happen in that  
“ country.” The same author tells us, in another place, that, “ during his stay at the city of Quito,  
“ or in the neighbourhood of it, there were two  
“ earthquakes, violent enough to overturn some  
“ houses in the country, which buried several persons  
“ under their ruins.”

#### S E C T. V.

82. It is generally found, that earthquakes in hilly countries, are much more violent than those, which happen elsewhere; and this is observed to be the case, as well when they take their rise from the lower countries, as amongst the hills themselves. This appearance being so easily to be accounted for, from the structure of the earth already described, I

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\* See Phil. Transf. N<sup>o</sup> 209, or Lowthorp’s Abr. vol. ii. p. 410.



shall content myself with establishing the certainty of a fact, which tends so greatly to confirm it.

83. The earthquakes that have infested some of the towns in the neighbourhood of Quito, have not only been incomparably more violent than that which destroyed Lisbon, but they seem to have exceeded that also which destroyed Lima and Callao. In \* Lisbon, many of the houses were left standing, although few of them were less than four or five stories high. At Lima also, it is only said, that "all the buildings, great and small, or at least the greatest part of them, were destroyed." Callao likewise, as it appears from the accounts we have of it, had many houses left unhurt by the earthquake, till the wave came, which overwhelmed the whole town, and threw down every thing that lay in its way. All these effects seem to be greatly short of those produced by an earthquake that happened at Latacunga, in the year 1698, when the whole town, consisting of more than six hundred houses, was entirely destroyed in less than three minutes time, a part of one only escaping; notwithstanding that the houses there are never built more than one story high, in order, if possible, to avoid these dangers. Ambato, a village about the same size as Latacunga, together with a great part of Riobamba, another town in the same neighbourhood, were also entirely destroyed by the same earthquake, and some others were either destroyed, or received considerable damage

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\* See *Philos. Trans.* vol. xlix. p. 403. where it is said, "of the dwelling-houses, there might be about one fourth of them that tumbled."

from it. At the same time, a volcano burst out suddenly in the neighbouring mountain of Carguayrafo, as before-mentioned; and, "near Ambato, the earth " opened itself in several places, and there yet remains, to the south of that town, a cleft of four " or five feet broad, and about a league in length, " lying north and south; there are also several other " like clefts on the other side of the river." The city of \* Quito was affected at the same time, but received no damage, though it is no more than forty-two geographical miles from Latacunga, not far from whence the greatest violence of the shock seems to have exerted itself. These towns are supposed to stand by far the highest of any in the world, being as high above the level of the sea, as the tops of some of the highest mountains in Europe; and the ground upon which Riobamba stands, wants but † ninety yards of being three times as high as Snowdon, the highest mountain in Wales.

84. The country upon which these towns stand, serves as a base, from whence arise another set of high lands and mountains, which are much the highest in the known world. Amongst these mountains there are no less than six volcanos, if not more,

\* The city of Quito stands lower than the level of Riobamba, by about 500 yards perpendicular. Though it escaped this, it has lately, however, been destroyed by another violent earthquake, that happened on the 28th April 1756, of which I have not yet seen any other particulars worth notice.

† This is according to Antonio d'Ulloa's account; but Mons. Condamine makes it exactly three times the height of Snowdon, computing it at 1770 toises. [See his measure of a degree of the meridian.]

within an extent of 120 miles long, and less than thirty broad, the lowest of which exceeds the height of Riobamba by above two thirds of a mile, and the highest by more than twice that quantity. Now, as the earthquakes have been more violent at the foot of these mountains, than in the lower lands, so they have been still more violent towards the tops of them: this is sufficiently manifest, from the many \* rents made in them, and the rocks that have been broken off from them, upon such occasions: but it appears still more manifestly, and beyond all dispute, in the bursting forth of volcanos, which are almost always at the very † summit of the mountains, where they are found. In these instances, the earth, stones, &c. which lay over the fire, are generally scattered by the violence of the vapour, that breaks its way through, to the distance of some miles round about.

85. The great earthquake of the 1st November 1755, was also more violent amongst the mountains, than at the city of Lisbon. We are told, that “ the mountains of Arrabida, Estrella, Julio, Marvan, and Cintra, being some of the largest in Portugal, were impetuously shaken, as it were, from their very foundations; and most of them opened at their summits, split and rent in a wonderful manner, and huge masses of them were thrown down into the subjacent vallies ‡.”

\* See d'Ulloa's Voyage to Peru, part i. book vi. chap. 2.

† The only exceptions that I know of to this rule, are in those cases, where the highest part having an opening already, some fresh mouth opens itself in the side of the mountain.

‡ See Hist. and Philos. of Earthq. p. 317.

86. The same was observed at Jamaica likewise. In the earthquake that destroyed Port-Royal in 1692, we are told, that “ more houses were left standing  
 “ at that town, than in all the island besides. It was  
 “ so violent in other places, that people were violently  
 “ thrown down on the ground, where they lay with  
 “ their legs and arms spread out, to prevent being  
 “ tumbled about by the incredible motion of the  
 “ earth. It scarce left a planter’s house or sugar-  
 “ work standing all over the island: I think it left  
 “ not a house standing at Passage fort, and but one  
 “ in all Liganee, and none in St. Iago, except a few  
 “ low houses, built by the wary Spaniards. In Cla-  
 “ rendon precinct, the earth gaped, and spouted up,  
 “ with a prodigious force, great quantities of water  
 “ into the air, twelve miles from the sea; and all  
 “ over the island, there were abundance of openings  
 “ of the earth, many thousands. But in the moun-  
 “ tains, are said to be the most violent shakes of all;  
 “ and it is a generally received opinion, that the  
 “ nearer to the mountains, the greater the shake;  
 “ and that the cause thereof, whatever it is, lies  
 “ there. Indeed they are strangely torn and rent,  
 “ especially the blue, and other highest mountains,  
 “ which seem to be the greatest sufferers, and which,  
 “ during the time that the great shakes continued,  
 “ bellowed out prodigious loud noises and echo-  
 “ ings.

87. “ Not far from Yallowes, a mountain, after  
 “ having made several moves, overwhelmed a whole  
 “ family, and a great part of a plantation, lying a  
 “ mile off; and a large high mountain near Port-  
 “ morant,

“ morant, near a day’s journey over, is said to be  
 “ quite swallowed up.

88. “ In the blue mountains, from whence came  
 “ those dreadful roarings, may reasonably be sup-  
 “ posed to be many strange alterations of the like  
 “ nature; but those wild desert places being very  
 “ rarely, or never visited by any body, we are yet  
 “ ignorant of what happened there; but whereas  
 “ they used to afford a fine green prospect, now one  
 “ half part of them, at least, seem to be wholly de-  
 “ prived of their natural verdure \*.”

#### S E C T. VI.

89. I have supposed, that fires lying at the greatest depths generally produce the most extensive earthquakes; we must, however, except from this rule those cases where the depths are very great: for, as the weight of three miles perpendicular of common earth is capable of absolutely repressing the vapour of inflamed gunpowder, so we may well suppose, that

\* See *Philos. Trans.* N<sup>o</sup> 209. or *Lowthorp’s Abridg.* vol. ii. p. 416, &c. where there is a great deal more to the same purpose. See also *Hist. and Philos. of Earthq.* p. 286 and 287.

From the authorities quoted in this section, it appears, how little reason there is for the notion, that either large cities, or towns situated near the sea-coast, are more subject to violent earthquakes than others: it is not, however, much to be wondered at, that such a notion should have prevailed, after the great destruction that happened in so large and populous a city as Lisbon; since the demolition of a few ruinous houses only, in such a place, would have affected the imaginations of men more, and would have been more talked of, than the subversion of whole mountains in some wild and desert country, where at most half a dozen unknown shepherds might feel the effects of it, or perhaps only see it at a distance.

there

there may be a quantity of earth sufficient to repress the vapour of water, and keep it within its original limits, though ever so much heated. Now, whenever this is the case, it is manifest, that it can produce no effect: or, it may happen, that though the quantity of earth may not be sufficient absolutely to repress the vapour, yet it may be so great, as to suffer it to expand but very little: in this case, an earthquake arising from it would be but of small extent; the wave-like motion would be little or none; the vibratory motion would be felt every-where; and the propagation of the motion would be very quick. This last circumstance being almost the only one, by which these earthquakes can be known from those which owe their origin to shallower fires, it must be very difficult to distinguish them with certainty, as it is almost impossible to distinguish the difference of the time of their happening in different places, when the whole, perhaps, is comprehended within the space of two or three minutes; possibly, however, some of the earthquakes, which we have had in England, may have been of this class.

## S E C T. VII.

90. If we would inquire into the place of the origin of any particular earthquake, we have the following grounds to go upon.

91. *First*, The different directions, in which it arrives at several distant places: if lines be drawn in these directions, the place of their common intersection must be nearly the place sought: but this is liable to great difficulties; for there must necessarily be great uncertainty in observations, which cannot, at best,

best, be made with any great precision, and which are generally made by minds too little at ease to be nice observers of what passes; moreover, the directions themselves may be somewhat varied, by the inequalities in the weight of the superincumbent matter, under which the vapour passes, as well as by other causes.

92. *Secondly*, We may form some judgment concerning the place of the origin of a particular earthquake, from the time of its arrival at different places; but this also is liable to great difficulties. In both these methods, however, we may come to a much greater degree of exactness, by taking a medium amongst a variety of accounts, as they are related by different observers. But,

93. *Thirdly*, We may come to the greatest degree of exactness in those cases, where earthquakes have their source from under the ocean; for, in these instances, the proportional distance of different places from that source may be very nearly ascertained, by the interval between the earthquake and the succeeding wave: and this is the more to be depended on, as people are much less likely to be mistaken in determining the time between two events, which follow one another at a small interval, than in observing the precise time of the happening of some single event.

94. Let us now, by way of example, endeavour to inquire into the situation of the cause, that gave rise to the earthquake of the 1st of November 1755, the place of which seems to have been under the ocean, somewhere between the latitudes of Lisbon and Oporto, (though probably somewhat nearer to  
the

the former) and at the distance, perhaps, of ten or fifteen leagues from the coast. For,

95. *First*, The direction, in which the earthquake arrived at Lisbon, was from the north-west; at Madeira it came from the north-east; and in England it came from the south-west; all of which perfectly agree with the place assumed\*.

96. *Secondly*, The times in which the earthquake arrived at different places, agree perfectly well also with the same point. And,

97. *Thirdly*, The interval between these, and the time of the arrival of the subsequent wave, concur in confirming it. That all this might appear the better, I have subjoined the following table, assuming the point, from whence I compute, at the distance of about a degree of a great circle from Lisbon, and a degree and half from Oporto. In consequence of this supposition, I have added three minutes to the interval between the time when the shock was felt at Lisbon, and at the several other places. The first column in the table contains the names of places; the second, the distances from the assumed point, reckoned in half degrees; the third, the time that the earthquake took up in travelling to each, expressed in minutes; and the fourth contains the time in which the wave was propagated, from its source to the respective places, expressed in minutes likewise.

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\* All these directions, together with the times when the earthquake, as well as the succeeding wave, arrived at different places, (two or three only excepted) are taken from the 49th volume of the *Philos. Trans.* and the *Hist. and Philos. of Earthq.* To these, I must refer the reader for the particular authorities, which, as they are very numerous, I was not willing to quote at length.



	Half deg.	Min.	Min.
Lisbon * - - - - -	2	3	12
Oporto * - - - - -	3	5	
Ayamonte - - - - -	6		53
Cadiz - - - - -	9	12	82
Madrid - - - - -	9	11	
Gibraltar - - - - -	11	18	
Madeira - - - - -	19	25	152
Mountsbay - - - - -	20		267
Plymouth - - - - -	21		360
Portsmouth - - - - -	23	29	
Kingfale - - - - -	23		290
Swansea - - - - -	24		530
The Hague - - - - -	30	32	
Lochnes - - - - -	33	66	
Antigua - - - - -	98		565
Barbadoes - - - - -	101		485

98. In computing the times in the preceding table, allowance was made for the difference of longitude, as it is laid down in the common maps, which are

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\* It appears, by all the accounts, that the interval between the earthquake and wave, either at Oporto or Lisbon, was not long: I have met with no account yet, however, which tells us how long it was at the former, and only one which mentions it at the latter, where it is said to have been nine minutes. [See *Memoires sur les tremblemens de Terre*, p. 245. compared with *Hist. of Earthquakes*, p. 315.] These intervals, if we knew them exactly, might have served, perhaps, to ascertain the distance of those two places from the original source a little more accurately; but, as the distance of neither from thence could be very great, a small difference in them would hardly sensibly affect any of the others; from which, therefore, we may draw the same general conclusions, as if they were exact.

not

not always greatly to be depended on. The times themselves also are often so carelessly observed, as well as vaguely related, that they are many of them subject to considerable errors; the concurrent testimonies, however, are so many, that there can be no doubt about the main point; and, that the errors might be as small as possible, I have not only endeavoured to select those accounts that had the greatest appearance of accuracy, but, in all cases where it was to be had, I have always taken a mean amongst them. In many of the accounts, the relaters say only between such hours, or about such an hour: of this kind were the accounts of the times of the agitation of the waters at The Hague and Lochness, which vary the most from a medium of the rest, the former erring about seven minutes in defect, and the latter about twenty minutes in excess; with regard to the latter, however, I must observe, that, from the account itself, it is probable the agitation happened sooner than eleven o'clock, which is the time mentioned. The accounts also of the time of the agitation of the waters in the northern parts of England, seem to confirm the same thing\*.

99. It is observable, in the preceding table, that the times, which the wave took up in travelling, are

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\* As the shortest way that the vapour could pass from near Lisbon to Lochness was under the ocean, possibly it might, on that account, be somewhat retarded; for the water adding to the weight of the superincumbent mass, and not to its elasticity, must produce this effect in some degree; it is probable, however, that this could make no great difference, as the motion seems to have been very little retarded in its passage from the original source to Madeira, to which place, I suppose, it must have passed under deeper seas than would be found in its road to Scotland.

not in the same proportion with the distances of the respective places from the supposed source of the motion; this, however, is no objection against the point assumed, since it is manifest, wherever it was, that it could not be far from Lisbon, as well because the wave arrived there so very soon after the earthquake, as because it was so great, rising, as we are told, at the distance of three miles from Lisbon, to the height of fifty or sixty feet. The true reason of this disproportion, seems to be the difference in the depth of the water; for, in every instance in the above table, the time will be found to be proportionably shorter or longer, as the water through which the wave passed was \* deeper or shallower. Thus the motion of the wave to Kingsale or Mountsbay (through waters not deeper in general than 200 fathoms) was slower than that to Madeira, (where the waters are much deeper) in the proportion of about three to five; and it was slower than that to Barbadoes, (where its course lay through the deepest part of the Atlantic ocean) nearly in the proportion of one to three: so likewise the motion of it from the Scilly islands to Swansea in Wales (where the depth gradually diminishes from about sixty or seventy fathoms to a very small matter) was still slower than that to Kingsale, in the proportion of less than one to three: the same thing is observable with regard to

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\* We have an instance to this purpose in the tides, which, in deep waters, move with a velocity that would carry them round the whole earth in a single day; but as they get into shallower waters, they are greatly retarded: and we are told, that in the river of Amazons, the same tide is found running up to the tenth or twelfth day, before it is entirely spent. [See *Condamine's Voyage down the Maranon.*]

Plymouth also, where the wave arrived about ninety minutes later than at Mountbay, though the difference of their distance from the first source could not, upon any supposition, be more than forty or fifty miles.

### S E C T. VIII.

100. If we would inquire into the depth, at which the cause lies, that occasions any particular earthquake, I know of no method of determining it, which does not require observations not yet to be had; but if such could be procured, and they were made with sufficient accuracy, I think some kind of guess might be formed concerning it: for,

101. *First*, In those instances, where the vapour discharges itself at the mouths of volcanos, (as in the case of the earthquake at Lima) it might, perhaps, be possible for a careful observer to trace the \* thickness of the several strata from thence to the place where the earthquake took its rise, or at least as far as the shore, if it took its rise from under the sea. If this could be once done in any one instance, and the velocity of such an earthquake nicely determined, we might then guess at the depth of the cause in other earthquakes, where we knew their velocity, by taking the † depths proportional to those velocities, which probably would answer very nearly.

102. *Secondly*, If, in any instance, it should be possible to know how much the motion of any earthquake was retarded by passing under the ocean, the

\* This is upon the supposition, that the under strata, in ascending up the hills, come to the day in the manner before described. See art. 43. and Fig. 3.

† See the note to art. 63.

depth of the ocean being known, the depth at which the vapour passed would be known also; for the velocity under the water would be to the velocity, if there had been no water, in the subduplicate ratio of the weight in the latter case to the weight in the former; hence allowing earth to be about two and half times the weight of water, the depth will be readily found.

103. *Thirdly*, Let us conceive the earth to be formed according to the idea before given of it, and that the same strata are at a medium of the same thickness for a very great extent, as well in those places, where several of the upper ones are wanting, as where they are not. Upon this supposition, we may discover the depth, at which the vapour passes, by comparing the several velocities of the same earthquake in places, where the \* thicknesses of the superincumbent mass are different. It must be acknowledged, indeed, that such observations with regard to time, as would enable us to determine these velocities, are in general much too nice to be expected: the matter, however, is not altogether desperate, as we may collect them, in some measure perhaps, from other circumstances, such, for instance, as the degree of † agitation in different waters, the proportional ‡ suddenness, with which the earth is lifted in different places, &c.

104. As

\* In order to know this difference, it will be necessary to trace the thickness of those strata, which are found in some of the places, but are wanting in others.

† See art. 71 and 72.

‡ This may be known from the distance to which the mercury subsides in the barometer, upon the first raising of the earth by the vapour.

104. As the observations relating to the earthquake of the 1st of November 1755 are too gross, it would be in vain to attempt, by any of the foregoing methods, to determine with any certainty the depth at which the cause of it lay; but, if I might be allowed to form a random guess about it, I should suppose, (upon a comparison of all circumstances) that it could not be much less than a mile, or a mile and half, and I think it is probable, it did not exceed three miles.

### C O N C L U S I O N.

105. Thus have I endeavoured to shew how the principal phænomena of earthquakes may be produced, by a cause with which none, that I have seen, appear to me to be incompatible. As I have not knowingly misrepresented any fact, so neither have I designedly omitted any that appeared to affect the main question; but, that I might not unnecessarily swell what had already much exceeded the limits at first intended for it, I have omitted,

106. *First*, Those minuter appearances, which almost every reader would easily account for, from what has been said already, and which did not seem to lead to any thing farther: such, for instance, are the sudden stopping and gushing out of fountains, occasioned by the opening or contracting of fissures; the dizziness and sickness people feel, from the almost imperceptible wave-like motion, &c.

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vapour. I don't find, that this phænomenon, which is a common attendant on earthquakes, was observed any-where, at the time of the earthquake of the 1st of November 1755, except at Amsterdam, where the mercury subsided more than an inch. See Hist. and Philos. of Earthq. p. 309.

107. *Secondly*, Those appearances which seemed to depend upon particular circumstances, and of which, therefore, unless we had a more exact knowledge of the countries where they happened, it would have been impossible to give any account, without having recourse to uncertain conjectures; of this kind, was the greater agitation of the waters in the lakes of Switzerland, at the time of the earthquake of the 1st of November 1755, than during the \* earthquake of the 9th of December following, though the houses upon the borders of them were more violently shaken by the latter. And,

108. *Lastly*, Those appearances, which only seem to have an accidental connection with earthquakes, or the causes of them; of this kind, are the effects which, in some instances perhaps, they produce on the weather; the distempers which are sometimes said to succeed them; the disturbance which, we are told, they have sometimes occasioned, during the shocks, in the direction of the magnetic needle, &c. none of which are observed to be constant attendants on earthquakes, nor do they seem materially to affect the solution given either one way or other.

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\* See Monsieur Bertrand's *Memoires sur les tremblemens de Terre*.